

WEIGHTED OSCILLATOR STRENGTHS AND LIFETIMES FOR THE Si VI SPECTRUM

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ABSTRACT

The weighted oscillator strengths (gf) and the lifetimes for Si VI presented in this work were carried out in a multiconfiguration Hartree-Fock relativistic (HFR) approach. In this calculation, the electrostatic parameters were optimized by a least squares procedure, in order to improve the adjustment to experimental energy levels. This method produces gf -values that are in better agreement with intensity observations and lifetime values that are closer to the experimental ones. In this work we presented all the experimentally known electric dipole Si VI spectral lines.

Subject heading: atomic data

1. INTRODUCTION

The ground state configuration of five times ionized silicon, Si VI, is $1s^2 2s^2 2p^5$ with the term 2P . Si VI belongs to the F I isoelectronic sequence. The ionization potential for Si VI is 1653900 cm^{-1} (205.06 eV). The spectrum was analyzed for the first time by Söderqvist (1934) and Ferner (1941) in the grating incidence region 65–250 Å. In 1971, Moore summarized the energy levels of Söderqvist (1934) and Ferner (1941). Griffin, Pegg, & Sellin (1976) and Träbert et al. (1976), using the beam-foil technique studied the spectra of highly ionized stripped silicon ions in the extreme ultraviolet and some Si VI lines were classified. Artru & Brillet (1977) extended the analysis of this spectrum into the VUV region. Furthermore, they improved the accuracy of the majority of the known levels. Kelly (1987) summarized all the wavelengths published for Si VI. Trigueiros et al. (1991, 1992) using laser produced plasmas analyzed the spectrum of Si VI in the VUV region.

The purpose of this work is to present a review of all known electric dipole transitions of Si VI, their oscillator strengths calculated from fitted values of the energy parameters and the lifetimes, calculated by the same method, for all known experimental energy levels. The work we present here was stimulated by the desire to determine weighted oscillator strengths and lifetimes for the Si VI spectrum. Both parameters are important in the study of laboratory and solar spectra, as silicon is an astrophysically important element. No extensive source of gf and lifetime values currently exists for this element.

2. CALCULATION

The oscillator strength $f(\gamma\gamma')$ is a physical quantity related to line intensity I and transition probability $W(\gamma\gamma')$, as given by Sobelman (1979):

$$W(\gamma\gamma') = \frac{2\omega^2 e^2}{mc^3} |f(\gamma\gamma')|, \quad (1)$$

with

$$I \propto gW(\gamma\gamma') \propto g|f(\gamma\gamma')| = gf.$$

Here m is the electron mass, e is the electron charge, γ is the initial quantum state, $\omega = [E(\gamma) - E(\gamma')]/\hbar$, $E(\gamma)$ is the initial state energy, $g = (2J + 1)$ is the number of degenerate quantum states with angular momentum J (in the formula for the initial state). Quantities with primes refer to the final state.

In the equation above, the weighted oscillator strength, gf , is given by Cowan (1981):

$$gf = \frac{8\pi^2 m c a_0^2 \sigma}{3h} S, \quad (2)$$

where $\sigma = |E(\gamma) - E(\gamma')|/\hbar c$, h is Planck's constant, c is light velocity, a_0 is the Bohr radius, and the electric dipole line strength is defined by

$$S = |\langle \lambda J \| \mathbf{P}^1 \| \gamma' J' \rangle|^2. \quad (3)$$

This quantity is a measure of the total strength of the spectral line, including all possible transitions between m, m' different J_z eigenstates. The tensor operator \mathbf{P}^1 (first order) in the reduced matrix element is the classical dipole moment for the atom in units of $-ea_0$.

To obtain gf , we need to calculate S first, or its square root:

$$S_{\gamma\gamma'}^{1/2} = \langle \gamma J \| \mathbf{P}^1 \| \gamma' J' \rangle. \quad (4)$$

In a multiconfiguration calculation we have to expand the wavefunction $|\gamma J\rangle$ in terms of single configuration wavefunctions, $|\beta J\rangle$, for both upper and lower levels:

$$|\gamma J\rangle = \sum_{\beta} y_{\beta J}^{\gamma} |\beta J\rangle. \quad (5)$$

Therefore, we can have the multiconfigurational expression for $S_{\gamma\gamma'}^{1/2}$:

$$S_{\gamma\gamma'}^{1/2} = \sum_{\beta} \sum_{\beta'} y_{\beta J}^{\gamma} \langle \beta J \| \mathbf{P}^1 \| \beta' J' \rangle y_{\beta' J'}^{\gamma'} \quad (6)$$

The probability per unit time of an atom in a specific state γJ to make a spontaneous transition to any state with lower energy is

$$P(\gamma J) = \sum A(\gamma J, \gamma' J'), \quad (7)$$

where $A(\gamma J, \gamma' J')$ is the Einstein spontaneous emission transition probability rate for a transition from the γJ to the $\gamma' J'$ state. The sum is over all $\gamma' J'$ states with $E(\gamma' J') < E(\gamma J)$.

The Einstein probability rate is related to gf through the following relation given by Cowan (1981):

$$gA = \frac{8\pi^2 e^2 \sigma^2}{mc} gf. \quad (8)$$

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TABLE 1
WEIGHTED OSCILLATOR STRENGTHS AND SPECTRAL LINES FOR THE Si VI SPECTRUM

gf -VALUE ^a	INT. ^b	WAVELENGTHS ^c (Å)		LEVELS ^d (cm ⁻¹)		CONFIGURATIONS ^e		TERMS ^e	J - J°	REF.
		Observed	Calculated	Lower	Upper					
1.03×10^{-1}	20	65.004	65.003	0	1538386	$1s^2 2s^2 2p^5$	$2s^2 2p^4(^1D)5d$	$2P^{\circ-2}S$	3/2-1/2	1
1.66×10^{-2}	10	65.211	65.219	5090	1538386	$2s^2 2p^5$	$2s^2 2p^4(^1D)5d$	$2P^{\circ-2}S$	1/2-1/2	1
5.60×10^{-1}	20	66.772	66.771	0	1497653	$2s^2 2p^5$	$2s^2 2p^4(^3P)5d$	$2P^{\circ-2}D$	3/2-5/2	1
4.24×10^{-2}	10	66.796	66.796	0	1497095	$2s^2 2p^5$	$2s^2 2p^4(^1S)4d$	$2P^{\circ-2}D$	3/2-5/2	1
3.37×10^{-1}	50	69.204	69.204	0	1445003	$2s^2 2p^5$	$2s^2 2p^4(^1D)4d$	$2P^{\circ-2}D$	3/2-5/2	1
1.59×10^{-1}	250	69.236	69.236	0	1444335	$2s^2 2p^5$	$2s^2 2p^4(^1D)4d$	$2P^{\circ-2}S$	3/2-1/2	1
2.20×10^{-1}	50	69.421	69.421	5090	1445575	$2s^2 2p^5$	$2s^2 2p^4(^1D)4d$	$2P^{\circ-2}D$	1/2-3/2	1
8.23×10^{-2}	100	69.448	69.447	5090	1445027	$2s^2 2p^5$	$2s^2 2p^4(^1D)4d$	$2P^{\circ-2}P$	1/2-3/2	1
3.02×10^{-1}	250	71.181	71.181	0	1404870	$2s^2 2p^5$	$2s^2 2p^4(^3P)4d$	$2P^{\circ-2}D$	3/2-5/2	1
2.17×10^{-2}	100	71.273	71.272	0	1403085	$2s^2 2p^5$	$2s^2 2p^4(^3P)4d$	$2P^{\circ-2}D$	3/2-3/2	1
3.34×10^{-2}	10	71.304	71.303	0	1402472	$2s^2 2p^5$	$2s^2 2p^4(^3P)4d$	$2P^{\circ-2}P$	3/2-1/2	1
1.61×10^{-2}	50	71.340	71.339	0	1401755	$2s^2 2p^5$	$2s^2 2p^4(^3P)4d$	$2P^{\circ-4}P$	3/2-5/2	1
1.00×10^{-4}	150	71.366	71.366	5090	1406317	$2s^2 2p^5$	$2s^2 2p^4(^3P)4d$	$2P^{\circ-2}P$	1/2-3/2	1
2.35×10^{-2}	200	71.384	71.384	0	1400877	$2s^2 2p^5$	$2s^2 2p^4(^3P)4d$	$2P^{\circ-4}P$	3/2-3/2	1
1.89×10^{-1}	50	71.474	71.474	0	1399117	$2s^2 2p^5$	$2s^2 2p^4(^3P)4d$	$2P^{\circ-4}F$	3/2-5/2	1
3.33×10^{-1}	50	71.534	71.531	5090	1403085	$2s^2 2p^5$	$2s^2 2p^4(^3P)4d$	$2P^{\circ-2}D$	1/2-3/2	1
5.47×10^{-2}	50	71.561	71.562	5090	1402472	$2s^2 2p^5$	$2s^2 2p^4(^3P)4d$	$2P^{\circ-2}P$	1/2-1/2	1
2.00×10^{-4}	10	71.644	71.644	5090	1400877	$2s^2 2p^5$	$2s^2 2p^4(^3P)4d$	$2P^{\circ-4}P$	1/2-3/2	1
1.03×10^{-1}	10	71.718	71.718	5090	1399439	$2s^2 2p^5$	$2s^2 2p^4(^3P)4d$	$2P^{\circ-4}F$	1/2-3/2	1
3.94×10^{-2}	50	72.896	72.892	0	1371884	$2s^2 2p^5$	$2s^2 2p^4(^1D)4s$	$2P^{\circ-2}D$	3/2-5/2	1
4.21×10^{-2}	200	75.193	75.191	0	1329941	$2s^2 2p^5$	$2s^2 2p^4(^3P)4s$	$2P^{\circ-2}P$	3/2-3/2	1
7.20×10^{-3}	50	75.486	75.480	5090	1329941	$2s^2 2p^5$	$2s^2 2p^4(^3P)4s$	$2P^{\circ-2}P$	1/2-3/2	1
1.14×10^{-2}	50	75.587	75.398	0	1326302	$2s^2 2p^5$	$2s^2 2p^4(^3P)4s$	$2P^{\circ-4}P$	3/2-3/2	1
3.75×10^{-1}	500	77.429	77.429	0	1291505	$2s^2 2p^5$	$2s^2 2p^4(^1S)3d$	$2P^{\circ-2}D$	3/2-5/2	1
2.72×10^{-1}	300	77.718	77.718	5090	1291798	$2s^2 2p^5$	$2s^2 2p^4(^1S)3d$	$2P^{\circ-2}D$	1/2-3/2	1
1.97×10^{-1}	250	80.395	80.394	0	1243878	$2s^2 2p^5$	$2s^2 2p^4(^1D)3d$	$2P^{\circ-2}D$	3/2-3/2	1
1.59×10^0	500	80.449	80.450	0	1243012	$2s^2 2p^5$	$2s^2 2p^4(^1D)3d$	$2P^{\circ-2}D$	3/2-5/2	1
2.11×10^{-1}	250	80.491	80.489	0	1242408	$2s^2 2p^5$	$2s^2 2p^4(^1D)3d$	$2P^{\circ-2}P$	3/2-1/2	1
7.83×10^{-2}	500	80.501	80.503	0	1242190	$2s^2 2p^5$	$2s^2 2p^4(^1D)3d$	$2P^{\circ-2}F$	3/2-5/2	1
1.33×10^0	600	80.577	80.578	0	1241035	$2s^2 2p^5$	$2s^2 2p^4(^1D)3d$	$2P^{\circ-2}P$	3/2-3/2	1
6.00×10^{-1}	500	80.698	80.698	0	1239194	$2s^2 2p^5$	$2s^2 2p^4(^1D)3d$	$2P^{\circ-2}S$	3/2-1/2	1
1.01×10^0	500	80.725	80.724	5090	1243878	$2s^2 2p^5$	$2s^2 2p^4(^1D)3d$	$2P^{\circ-2}D$	1/2-3/2	1
6.27×10^{-1}	400	80.821	80.820	5090	1242408	$2s^2 2p^5$	$2s^2 2p^4(^1D)3d$	$2P^{\circ-2}P$	1/2-1/2	1
2.91×10^{-1}	400	80.908	80.910	5090	1241035	$2s^2 2p^5$	$2s^2 2p^4(^1D)3d$	$2P^{\circ-2}P$	1/2-3/2	1
2.13×10^{-1}	350	81.030	81.030	5090	1239194	$2s^2 2p^5$	$2s^2 2p^4(^1D)3d$	$2P^{\circ-2}S$	1/2-1/2	1
3.09×10^{-1}	200	83.006	83.012	0	1204647	$2s^2 2p^5$	$2s^2 2p^4(^3P)3d$	$2P^{\circ-2}P$	3/2-3/2	1
1.27×10^0	750	83.128	83.134	0	1202880	$2s^2 2p^5$	$2s^2 2p^4(^3P)3d$	$2P^{\circ-2}D$	3/2-5/2	1
7.03×10^{-2}	250	83.258	83.264	0	1201002	$2s^2 2p^5$	$2s^2 2p^4(^3P)3d$	$2P^{\circ-2}D$	3/2-3/2	1
5.95×10^{-2}	50	83.283	83.284	0	1200714	$2s^2 2p^5$	$2s^2 2p^4(^3P)3d$	$2P^{\circ-2}P$	3/2-1/2	1
4.00×10^{-4}	400	83.358	83.364	5090	1204647	$2s^2 2p^5$	$2s^2 2p^4(^3P)3d$	$2P^{\circ-2}P$	1/2-3/2	1
1.46×10^{-2}	400	83.526	83.491	0	1197733	$2s^2 2p^5$	$2s^2 2p^4(^3P)3d$	$2P^{\circ-4}P$	3/2-5/2	1
8.26×10^{-1}	400	83.611	83.618	5090	1201002	$2s^2 2p^5$	$2s^2 2p^4(^3P)3d$	$2P^{\circ-2}D$	1/2-3/2	1
8.40×10^{-2}	150	83.639	83.638	5090	1200714	$2s^2 2p^5$	$2s^2 2p^4(^3P)3d$	$2P^{\circ-2}P$	1/2-1/2	1
3.00×10^{-3}	50	83.684	83.689	0	1194905	$2s^2 2p^5$	$2s^2 2p^4(^3P)3d$	$2P^{\circ-2}P$	3/2-1/2	1
1.03×10^{-1}	50	83.729	83.729	0	1194332	$2s^2 2p^5$	$2s^2 2p^4(^3P)3d$	$2P^{\circ-4}F$	3/2-3/2	1
2.69×10^{-2}	300	83.802	83.806	0	1193227	$2s^2 2p^5$	$2s^2 2p^4(^3P)3d$	$2P^{\circ-4}F$	3/2-5/2	1
3.00×10^{-4}	10	83.965	83.970	5090	1195990	$2s^2 2p^5$	$2s^2 2p^4(^3P)3d$	$2P^{\circ-4}P$	1/2-3/2	1
1.96×10^{-2}	600	84.082	84.087	5090	1194332	$2s^2 2p^5$	$2s^2 2p^4(^3P)3d$	$2P^{\circ-4}F$	1/2-3/2	1
6.70×10^{-2}	200	91.370	91.371	0	1094444	$2s^2 2p^5$	$2s^2 2p^4(^1S)3s$	$2P^{\circ-2}S$	3/2-1/2	2
4.26×10^{-2}	200	91.798	91.798	5090	1094444	$2s^2 2p^5$	$2s^2 2p^4(^1S)3s$	$2P^{\circ-2}S$	1/2-1/2	2
2.03×10^{-2}	500	96.022	96.018	0	1041477	$2s^2 2p^5$	$2s^2 2p^4(^1D)3s$	$2P^{\circ-2}D$	3/2-3/2	2
1.94×10^{-1}	500	96.488	96.489	5090	1041477	$2s^2 2p^5$	$2s^2 2p^4(^1D)3s$	$2P^{\circ-2}D$	1/2-3/2	2
1.02×10^{-1}	500	99.096	99.096	0	1009122	$2s^2 2p^5$	$2s^2 2p^4(^3P)3s$	$2P^{\circ-2}P$	3/2-1/2	2
4.88×10^{-1}	750	99.459	99.459	0	1005436	$2s^2 2p^5$	$2s^2 2p^4(^3P)3s$	$2P^{\circ-2}P$	3/2-3/2	2
1.86×10^{-1}	500	99.599	99.598	5090	1009122	$2s^2 2p^5$	$2s^2 2p^4(^3P)3s$	$2P^{\circ-2}P$	1/2-1/2	2
7.90×10^{-2}	500	99.966	99.965	5090	1005436	$2s^2 2p^5$	$2s^2 2p^4(^3P)3s$	$2P^{\circ-2}P$	1/2-3/2	2
6.00×10^{-4}	10	100.159	100.159	5090	993634	$2s^2 2p^5$	$2s^2 2p^4(^3P)3s$	$2P^{\circ-4}P$	1/2-3/2	2
7.50×10^{-3}	500	100.640	100.641	0	993634	$2s^2 2p^5$	$2s^2 2p^4(^3P)3s$	$2P^{\circ-4}P$	3/2-3/2	2
8.00×10^{-4}	40	100.953	100.957	0	990523	$2s^2 2p^5$	$2s^2 2p^4(^3P)3s$	$2P^{\circ-4}P$	3/2-5/2	2
9.00×10^{-4}	10	100.970	100.971	5090	995477	$2s^2 2p^5$	$2s^2 2p^4(^3P)3s$	$2P^{\circ-4}P$	1/2-1/2	2
9.50×10^{-2}	50	102.846	102.846	406497	1378824	$2s2p^6$	$2s2p^5(^3P)3s$	$2S-2P^{\circ}$	1/2-1/2	1
1.84×10^{-1}	100	103.163	103.163	406497	1375836	$2s2p^6$	$2s2p^5(^3P)3s$	$2S-2P^{\circ}$	1/2-3/2	1
9.00×10^{-5}	50	147.800	147.817	406497	1083009	$2s2p^6$	$2s^2 2p^4(^3P)3p$	$2S-4D^{\circ}$	1/2-1/2	3
9.00×10^{-5}	50	213.400	213.435	1069861	1538386	$2s^2 2p^4(^3P)3p$	$2s^2 2p^4(^1D)5d$	$4P^{\circ-2}S$	3/2-1/2	3

TABLE 1—Continued

gf -VALUE ^a	INT. ^b	WAVELENGTHS ^c (Å)		LEVELS ^d (cm ⁻¹)		CONFIGURATIONS ^e		TERMS ^e	J - J°	REF.
		Observed	Calculated	Lower	Upper					
1.46 × 10 ⁻²	50	224.100	224.109	1092176	1538386	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (¹ D)5d	² P ^o - ² S	3/2-1/2	3
4.04 × 10 ⁻¹	800	246.004	246.005	0	406497	2s ² 2p ⁵	2s2p ⁶	² P ^o - ² S	3/2-1/2	2,3
2.00 × 10 ⁻¹	700	249.124	249.124	5090	406497	2s ² 2p ⁵	2s2p ⁶	² P ^o - ² S	1/2-1/2	2,3
3.00 × 10 ⁻⁴		281.230	281.229	1182804	1538386	2s ² 2p ⁴ (¹ S)3p	2s ² 2p ⁴ (¹ D)5d	² P ^o - ² S	3/2-1/2	4
8.50 × 10 ⁻³	50	281.300	281.314	1089553	1445027	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (¹ D)4d	² D ^o - ² P	3/2-3/2	3
1.00 × 10 ⁻²		285.920	285.920	1147905	1497653	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (³ P)5d	² P ^o - ² D	3/2-5/2	4
9.00 × 10 ⁻⁵		301.250	301.251	1071134	1403085	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4d	⁴ P ^o - ² D	1/2-3/2	4
2.59 × 10 ⁻¹	2	308.481	308.481	1068819	1392988	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4d	⁴ P ^o - ⁴ D	5/2-5/2	5
5.49 × 10 ⁻¹	3	308.703	308.703	1068819	1392755	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4d	⁴ P ^o - ⁴ D	5/2-7/2	5
6.88 × 10 ⁻¹	8	314.348	314.348	1123549	1441668	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (¹ D)4d	² F ^o - ² G	5/2-7/2	5
8.91 × 10 ⁻¹	2	314.922	314.922	1124218	1441758	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (¹ D)4d	² F ^o - ² G	7/2-9/2	5
8.28 × 10 ⁻¹	6	315.094	315.094	1078940	1396306	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4d	⁴ D ^o - ⁴ F	7/2-9/2	5
4.80 × 10 ⁻¹	2	315.730	315.730	1080706	1397433	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4d	⁴ D ^o - ⁴ F	5/2-7/2	5
1.13 × 10 ⁻¹	2	318.025	318.025	1086802	1401243	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4d	² D ^o - ² F	5/2-7/2	5
1.53 × 10 ⁻¹	1	319.241	319.241	1089553	1402796	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4d	² D ^o - ² F	3/2-5/2	5
3.78 × 10 ⁻¹	4	321.900	321.925	1134500	1445156	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (¹ D)4d	² D ^o - ² F	5/2-7/2	5
9.00 × 10 ⁻⁵	50	331.200	331.100	1069861	1371884	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4s	⁴ P ^o - ² D	3/2-5/2	3,4
9.00 × 10 ⁻⁵	50	360.300	360.313	1124218	1401755	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (³ P)4d	² F ^o - ⁴ P	7/2-5/2	3
1.21 × 10 ⁻¹	2	386.430	386.433	1069861	1328637	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4s	⁴ P ^o - ⁴ P	3/2-1/2	5
1.04 × 10 ⁻¹	1	389.132	389.160	1147905	1404870	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (³ P)4d	² P ^o - ² D	3/2-5/2	5
5.12 × 10 ⁻¹	4	392.271	392.269	1068819	1323746	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4s	⁴ P ^o - ⁴ P	5/2-5/2	5
2.35 × 10 ⁻¹	3	393.874	393.878	1069861	1323746	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4s	⁴ P ^o - ⁴ P	3/2-5/2	5
5.30 × 10 ⁻¹	4	402.635	402.634	1123549	1371913	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (¹ D)4s	² F ^o - ² D	5/2-3/2	5
7.73 × 10 ⁻¹	8	403.770	403.770	1124218	1371913	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (¹ D)4s	² F ^o - ² D	7/2-5/2	5
1.94 × 10 ⁻¹	4	405.816	405.813	1082218	1328637	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4s	⁴ D ^o - ⁴ P	3/2-1/2	5
4.48 × 10 ⁻¹	5	407.161	407.174	1080706	1326302	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4s	⁴ D ^o - ⁴ P	5/2-3/2	5
7.63 × 10 ⁻¹	7	408.490	408.488	1078940	1323746	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4s	⁴ D ^o - ⁴ P	7/2-5/2	5
1.58 × 10 ⁻¹	2	409.695	409.696	1082218	1326302	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4s	⁴ D ^o - ⁴ P	3/2-3/2	5
1.62 × 10 ⁻¹	4	411.152	411.152	1089553	1332772	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4s	² D ^o - ² P	3/2-1/2	5
4.72 × 10 ⁻¹	4	411.278	411.286	1086801	1329941	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4s	² D ^o - ² P	5/2-3/2	5
1.01 × 10 ⁻¹	4	411.482	411.456	1080706	1323746	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4s	⁴ D ^o - ⁴ P	5/2-5/2	5
1.42 × 10 ⁻¹	1	416.001	415.993	1089553	1329941	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4s	² D ^o - ² P	3/2-3/2	5
3.04 × 10 ⁻¹	2	420.468	420.472	1134085	1371913	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (¹ D)4s	² D ^o - ² D	3/2-3/2	5
4.40 × 10 ⁻¹	3	421.238	421.258	1134500	1371884	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (¹ D)4s	² D ^o - ² D	5/2-5/2	5
1.09 × 10 ⁻¹	1	430.034	430.027	1093758	1326302	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)4s	⁴ S ^o - ⁴ P	3/2-3/2	5
4.35 × 10 ⁻¹	0	431.409	431.406	1181655	1413456	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₀)4f	⁴ D-[3] ^o	5/2-7/2	6
7.61 × 10 ⁻¹	2	433.607	433.640	1181173	1411779	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	⁴ D-[4] ^o	7/2-9/2	6
1.28 × 10 ⁻¹	1	434.782	434.806	1093758	1323746	2s ² 2p ⁴ (³ P)3p	2p ⁴ (³ P)4s	⁴ S ^o - ⁴ P	3/2-5/2	5
5.65 × 10 ⁻¹	1	436.281	436.281	1182317	1411527	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	⁴ D-[2] ^o	3/2-5/2	6
6.27 × 10 ⁻¹	2	437.512	437.513	1182900	1411464	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	⁴ D-[2] ^o	1/2-3/2	6
4.61 × 10 ⁰	7	442.951	440.659	1181173	1408106	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ D-[4] ^o	7/2-9/2	6
8.76 × 10 ⁻¹	2	443.531	443.532	1181655	1407118	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ D-[3] ^o	5/2-5/2	6
1.37 × 10 ⁻¹	5	443.814	443.814	1181655	1406975	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ D-[4] ^o	5/2-7/2	6
2.82 × 10 ⁻²	3	443.952	443.954	1182317	1407565	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ D-[2] ^o	3/2-3/2	6
1.44 × 10 ⁰	4	444.836	444.837	1182317	1407118	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ D-[3] ^o	3/2-5/2	6
8.38 × 10 ⁻¹	2	445.108	445.105	1182900	1407565	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ D-[2] ^o	1/2-3/2	6
2.50 × 10 ⁻¹	4	446.461	446.470	1147905	1371884	2s ² 2p ⁴ (¹ D)3p	2p ⁴ (¹ D)4s	² P ^o - ² D	3/2-5/2	5
1.00 × 10 ⁰	3	448.695	448.673	1232671	1455550	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² G-[4] ^o	9/2-9/2	6
2.30 × 10 ⁻²	3	448.695	448.701	1232671	1455537	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² G-[4] ^o	9/2-7/2	6
1.34 × 10 ⁻¹	1	451.213	451.210	1150287	1371913	2s ² 2p ⁴ (¹ D)3p	2p ⁴ (¹ D)4s	² P ^o - ² D	1/2-3/2	5
1.37 × 10 ⁻¹	9	452.171	452.171	1232671	1453827	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² G-[5] ^o	9/2-9/2	6
7.33 × 10 ⁰	9	452.171	452.171	1232671	1453827	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² G-[5] ^o	9/2-11/2	6
2.43 × 10 ⁰	5	454.058	454.065	1191546	1411779	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	⁴ F-[4] ^o	7/2-9/2	6
1.74 × 10 ⁰	3	456.295	456.292	1194332	1413490	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₀)4f	⁴ F-[3] ^o	3/2-5/2	6
2.69 × 10 ⁰	4	457.413	457.413	1193227	1411848	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	⁴ F-[4] ^o	5/2-7/2	6
7.49 × 10 ⁰	7	457.815	457.815	1189850	1408279	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ F-[5] ^o	9/2-11/2	6
6.49 × 10 ⁻¹	3	458.449	458.447	1194332	1412460	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ F-[3] ^o	3/2-5/2	6
9.97 × 10 ⁻¹	2	460.675	460.675	1189850	1408106	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ F-[4] ^o	9/2-9/2	6
3.06 × 10 ⁰	10	461.314	461.285	1194993	1411779	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	² F-[4] ^o	7/2-9/2	6
3.32 × 10 ⁰	10	461.314	461.320	1191546	1408316	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ F-[5] ^o	7/2-9/2	6
3.41 × 10 ⁻¹	0	461.767	461.766	1194905	1411464	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	⁴ P-[2] ^o	1/2-3/2	6
7.00 × 10 ⁻⁴	20	462.290	462.292	1182804	1399117	2s ² 2p ⁴ (¹ S)3p	2p ⁴ (³ P)4d	² P ^o - ⁴ F	3/2-5/2	2
8.01 × 10 ⁻¹	5	462.312	462.315	1197153	1413456	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₀)4f	² F-[3] ^o	5/2-7/2	6
1.41 × 10 ⁰	3	463.962	463.957	1195990	1411527	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	⁴ P-[2] ^o	3/2-5/2	6
1.80 × 10 ⁰	2	464.656	464.640	1197153	1412373	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	² F-[3] ^o	5/2-7/2	6

TABLE 1—Continued

<i>g</i> -VALUE ^a	INT. ^b	WAVELENGTHS ^c (Å)		LEVELS ^d (cm ⁻¹)		CONFIGURATIONS ^e		TERMS ^e	<i>J</i> - <i>J</i> ^e	REF.
		Observed	Calculated	Lower	Upper					
2.35 × 10 ⁰	6	465.881	465.896	1197733	1412373	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	⁴ P-[3] ^o	5/2-7/2	6
4.98 × 10 ⁻¹	1	467.735	467.740	1197733	1411527	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	⁴ P-[2] ^o	5/2-5/2	6
5.34 × 10 ⁻¹	1	467.897	467.886	1194905	1408632	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ P-[1] ^o	1/2-3/2	6
8.62 × 10 ⁻¹	2	468.149	468.149	1194905	1408512	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ P-[1] ^o	1/2-1/2	6
7.52 × 10 ⁻¹	3	468.530	468.530	1239194	1452628	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² S-[1] ^o	1/2-1/2	6
1.19 × 10 ⁰	3	468.530	468.530	1239194	1452628	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² S-[1] ^o	1/2-3/2	6
4.11 × 10 ⁰	8	468.780	468.722	1242190	1455537	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² F-[4] ^o	5/2-7/2	6
2.93 × 10 ⁰	8	468.780	468.774	1194993	1408316	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	² F-[5] ^o	7/2-9/2	6
1.25 × 10 ⁰	3	469.611	469.614	1242190	1455132	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² F-[3] ^o	5/2-5/2	6
3.40 × 10 ⁻²	3	469.611	469.614	1242190	1455132	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² F-[3] ^o	5/2-7/2	6
1.21 × 10 ⁻¹	7	469.728	469.778	1242670	1455537	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² F-[4] ^o	7/2-7/2	6
5.50 × 10 ⁰	7	469.728	469.748	1242670	1455537	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² F-[4] ^o	7/2-9/2	6
2.00 × 10 ⁰	3	469.832	469.833	1241035	1453877	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² P-[2] ^o	3/2-5/2	6
5.64 × 10 ⁻¹	1	470.263	470.274	1195990	1408632	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ P-[1] ^o	3/2-3/2	6
5.08 × 10 ⁻²	2	470.677	470.674	1242670	1455132	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² F-[3] ^o	7/2-5/2	6
1.54 × 10 ⁰	2	470.677	470.674	1242670	1455132	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² F-[3] ^o	7/2-7/2	6
3.00 × 10 ⁻⁴	1	471.021	471.007	1194993	1407304	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	² F-[3] ^o	7/2-7/2	6
5.44 × 10 ⁻²	3	471.433	471.433	1243012	1455132	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² D-[3] ^o	5/2-5/2	6
3.46 × 10 ⁰	3	471.433	471.433	1243012	1455132	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² D-[3] ^o	5/2-7/2	6
5.17 × 10 ⁻¹	1	471.873	471.738	1194993	1406975	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	² F-[4] ^o	7/2-7/2	6
6.44 × 10 ⁻²	1	472.228	472.226	1195990	1407753	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ P-[2] ^o	3/2-5/2	6
1.16 × 10 ⁰	3	472.860	472.859	1242408	1453888	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² P-[2] ^o	1/2-3/2	6
2.40 × 10 ⁰	3	473.366	473.365	1243878	1455132	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² D-[3] ^o	3/2-5/2	6
1.40 × 10 ⁰	4	474.238	474.238	1243012	1453877	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² D-[2] ^o	5/2-5/2	6
1.04 × 10 ⁰	2	475.000	475.002	1201002	1411527	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	² D-[2] ^o	3/2-5/2	6
7.95 × 10 ⁻²	3	475.850	475.848	1197153	1407304	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	² F-[3] ^o	5/2-7/2	6
8.91 × 10 ⁻¹	2	476.169	476.170	1243878	1453888	2s ² 2p ⁴ (¹ D)3d	2p ⁴ (¹ D ₂)4f	² D-[2] ^o	3/2-3/2	6
8.47 × 10 ⁻²	1	477.151	477.166	1197733	1407304	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	⁴ P-[3] ^o	5/2-7/2	6
1.92 × 10 ⁰	2	478.541	478.542	1202880	1411848	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	² D-[4] ^o	5/2-7/2	6
6.07 × 10 ⁻²	3	478.826	478.829	1204647	1412460	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₀)4f	² P-[3] ^o	3/2-5/2	6
2.17 × 10 ⁰	2	481.202	481.204	1204647	1412460	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	² P-[3] ^o	3/2-5/2	6
5.83 × 10 ⁻²	1	483.374	483.372	1204647	1411527	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₁)4f	² P-[2] ^o	3/2-5/2	6
7.04 × 10 ⁻¹	3	483.671	483.674	1201002	1407753	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	² D-[2] ^o	3/2-5/2	6
2.46 × 10 ⁻¹	1	485.165	485.162	1201002	1407118	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	² D-[3] ^o	3/2-5/2	6
1.06 × 10 ⁻¹	4	489.179	489.179	1202880	1407304	2s ² 2p ⁴ (³ P)3d	2p ⁴ (³ P ₂)4f	² D-[3] ^o	5/2-7/2	6
1.00 × 10 ⁻⁴		504.950	504.950	1093758	1291798	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (¹ S)3d	⁴ S ^o - ² D	3/2-3/2	4
6.83 × 10 ⁻²	90	690.350	690.363	1005436	1150287	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (¹ D)3p	² P- ² P ^o	3/2-1/2	2
4.32 × 10 ⁻¹	90	701.890	701.903	1005436	1147905	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (¹ D)3p	² P- ² P ^o	3/2-3/2	2
1.68 × 10 ⁻¹	60	708.394	708.394	1009122	1150287	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (¹ D)3p	² P- ² P ^o	1/2-1/2	2
9.61 × 10 ⁻²	40	720.547	720.550	1009122	1147905	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (¹ D)3p	² P- ² P ^o	1/2-3/2	2
3.89 × 10 ⁻¹	20	775.710	775.708	1068819	1197733	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ P	5/2-5/2	2
9.00 × 10 ⁻⁵	20	779.190	779.216	1068819	1197153	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ² F	5/2-5/2	2
2.81 × 10 ⁻¹	10	782.030	782.027	1069861	1197733	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ P	3/2-5/2	2
1.40 × 10 ⁻³	5	785.570	785.592	1069861	1197153	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ² F	3/2-5/2	2
2.19 × 10 ⁻¹	10	786.343	786.342	1068819	1195990	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ P	5/2-3/2	2
4.42 × 10 ⁻²	5	792.860	792.836	1069861	1195990	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ P	3/2-3/2	2
2.54 × 10 ⁻¹	30	799.723	799.718	1069861	1194905	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ P	3/2-1/2	2
3.18 × 10 ⁻¹	30	800.926	800.928	1071134	1195990	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ P	1/2-3/2	2
8.15 × 10 ⁻²	5	807.940	807.952	1071134	1194905	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ P	1/2-1/2	2
8.43 × 10 ⁻¹	20	844.219	844.226	1124218	1242670	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (¹ D)3d	² F ^o - ² F	7/2-7/2	2
9.00 × 10 ⁻⁴	5	874.990	874.993	1080706	1194993	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ D ^o - ² F	5/2-7/2	2
1.31 × 10 ⁻¹	10	884.640	884.647	1069861	1182900	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ D	3/2-1/2	2
6.68 × 10 ⁻¹	60	886.243	886.236	1068819	1181655	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ D	5/2-5/2	2
2.86 × 10 ⁻¹	10	888.050	888.056	1078940	1191546	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ D ^o - ⁴ F	7/2-7/2	2
4.12 × 10 ⁻¹	20	888.720	888.726	1080706	1193227	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ D ^o - ⁴ F	5/2-5/2	2
6.20 × 10 ⁻¹	50	889.227	889.230	1069861	1182317	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ D	3/2-3/2	2
1.79 × 10 ⁰	100	890.041	890.043	1068819	1181173	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ D	5/2-7/2	2
2.80 × 10 ⁻¹		891.970	891.954	1082218	1194332	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ D ^o - ⁴ F	3/2-3/2	2
7.97 × 10 ⁻¹	70	894.490	894.493	1069861	1181655	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ D	3/2-5/2	2
3.82 × 10 ⁻¹	40	894.737	894.734	1071134	1182900	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ D	1/2-1/2	2
7.91 × 10 ⁻¹	40	898.281	898.286	1083009	1194332	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ D ^o - ⁴ F	1/2-3/2	2
2.82 × 10 ⁻¹	40	899.427	899.422	1071134	1182317	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ P ^o - ⁴ D	1/2-3/2	2
1.55 × 10 ⁰	60	900.834	900.832	1082218	1193227	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ D ^o - ⁴ F	3/2-5/2	2
3.34 × 10 ⁰	200	901.637	901.637	1078940	1189850	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ D ^o - ⁴ F	7/2-9/2	2
2.37 × 10 ⁰	100	902.209	902.202	1080706	1191546	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ D ^o - ⁴ F	5/2-7/2	2

TABLE 1—Continued

<i>gf</i> -VALUE ^a	INT. ^b	WAVELENGTHS ^c (Å)		LEVELS ^d (cm ⁻¹)		CONFIGURATIONS ^e		TERMS ^e	<i>J</i> — <i>J</i> ^e	REF.
		Observed	Calculated	Lower	Upper					
4.19 × 10 ⁻¹	5	906.180	906.195	1086801	1197153	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	² D°— ² F	5/2—5/2	2
3.73 × 10 ⁻¹	30	919.034	919.031	1041477	1150287	2s ² 2p ⁴ (¹ D)3s	2s ² 2p ⁴ (¹ D)3p	² D— ² P°	3/2—1/2	2
3.35 × 10 ⁰	90	922.063	922.063	1124218	1232671	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (¹ D)3d	² F°— ² G	7/2—9/2	2
2.62 × 10 ⁰	100	924.290	924.286	1086801	1194993	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	² D°— ² F	5/2—7/2	2
1.72 × 10 ⁰	50	924.496	924.470	1134500	1242670	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (¹ D)3d	² D°— ² F	5/2—7/2	2
1.04 × 10 ⁰	5	925.030	925.026	1134085	1242190	2s ² 2p ⁴ (¹ D)3p	2s ² 2p ⁴ (¹ D)3d	² D°— ² F	3/2—5/2	2
1.46 × 10 ⁰		929.389	929.369	1089553	1193227	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	² D°— ⁴ F	3/2—5/2	2
6.64 × 10 ⁻¹		939.100	939.071	1041417	1147905	2s ² 2p ⁴ (¹ D)3s	2s ² 2p ⁴ (¹ D)3p	² D— ² P°	5/2—3/2	2
5.30 × 10 ⁻³	5	954.700	954.701	1086801	1191546	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	² D°— ⁴ F	5/2—7/2	2
1.05 × 10 ⁰	40	961.766	961.770	1093758	1197733	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ S°— ⁴ P	3/2—5/2	2
3.84 × 10 ⁻¹	60	968.655	968.657	990523	1093758	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ S°	5/2—3/2	2
1.09 × 10 ⁻¹	5	973.570	973.570	1078940	1181655	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ D°— ⁴ D	7/2—5/2	2
6.02 × 10 ⁻¹	70	978.167	978.161	1093759	1195990	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ S°— ⁴ P	3/2—3/2	2
5.76 × 10 ⁻¹	70	978.167	978.166	1078941	1181173	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ D°— ⁴ D	7/2—7/2	2
2.75 × 10 ⁻¹	30	988.664	988.667	1093758	1194905	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ S°— ⁴ P	3/2—1/2	2
1.83 × 10 ⁻¹	50	990.590	990.598	1080706	1181655	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ D°— ⁴ D	5/2—5/2	2
3.30 × 10 ⁻¹	60	997.884	998.755	993634	1093758	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ S°	3/2—3/2	2
4.77 × 10 ⁻²	5	1001.090	1001.091	1083009	1182900	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ D°— ⁴ D	1/2—1/2	2
5.58 × 10 ⁻²	5	1006.960	1006.963	1083009	1182317	2s ² 2p ⁴ (³ P)3p	2s ² 2p ⁴ (³ P)3d	⁴ D°— ⁴ D	1/2—3/2	2
1.89 × 10 ⁻¹	40	1017.470	1017.489	995477	1093758	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ S°	1/2—3/2	2
1.17 × 10 ⁰	50	1074.360	1074.309	1041417	1134500	2s ² 2p ⁴ (¹ D)3s	2s ² 2p ⁴ (¹ D)3p	² D— ² D°	5/2—5/2	2
1.18 × 10 ⁻¹	5	1074.980	1074.996	1041477	1134500	2s ² 2p ⁴ (¹ D)3s	2s ² 2p ⁴ (¹ D)3p	² D— ² D°	3/2—5/2	2
8.03 × 10 ⁻¹	30	1079.809	1079.809	1041477	1134085	2s ² 2p ⁴ (¹ D)3s	2s ² 2p ⁴ (¹ D)3p	² D— ² D°	3/2—3/2	2
2.38 × 10 ⁻¹	40	1108.850	1108.846	990523	1080706	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ D°	5/2—5/2	2
4.11 × 10 ⁻¹	30	1128.990	1128.860	993634	1082218	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ D°	3/2—3/2	2
1.71 × 10 ⁰	100	1130.983	1130.989	990523	1078940	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ D°	5/2—7/2	2
3.70 × 10 ⁻¹	50	1142.430	1142.443	995477	1083009	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ D°	1/2—1/2	2
9.98 × 10 ⁻¹	90	1148.630	1148.464	993634	1080706	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ D°	3/2—5/2	2
2.24 × 10 ⁻¹	70	1152.862	1152.867	1005436	1092176	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	² P— ² P°	3/2—3/2	2
4.13 × 10 ⁻¹	70	1152.862	1152.852	995477	1082218	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ D°	1/2—3/2	2
3.66 × 10 ⁻¹	50	1188.829	1188.811	1005436	1089553	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	² P— ² D°	3/2—3/2	2
3.42 × 10 ⁻¹	80	1204.050	1204.045	1009122	1092176	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	² P— ² P°	1/2—3/2	2
1.64 × 10 ⁰	200	1207.680	1207.707	1041417	1124218	2s ² 2p ⁴ (¹ D)3s	2s ² 2p ⁴ (¹ D)3p	² D— ² F°	5/2—7/2	2
1.09 × 10 ⁻¹	10	1217.416	1217.553	1041417	1123549	2s ² 2p ⁴ (¹ D)3s	2s ² 2p ⁴ (¹ D)3p	² D— ² F°	5/2—5/2	2
1.11 × 10 ⁰	100	1218.500	1218.435	1041477	1123549	2s ² 2p ⁴ (¹ D)3s	2s ² 2p ⁴ (¹ D)3p	² D— ² F°	3/2—5/2	2
1.16 × 10 ⁰	300	1229.010	1229.014	1005436	1086801	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	² P— ² D°	3/2—5/2	2
3.92 × 10 ⁻¹	50	1243.310	1243.306	1009122	1089553	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	² P— ² D°	1/2—3/2	2
8.72 × 10 ⁻¹	500	1277.200	1277.201	990523	1068819	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ P°	5/2—5/2	2
3.10 × 10 ⁻¹	100	1290.490	1290.303	993634	1071134	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ P°	3/2—1/2	2
1.07 × 10 ⁻¹	50	1312.640	1311.874	993634	1069861	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ P°	3/2—3/2	2
1.91 × 10 ⁻¹	90	1330.270	1330.049	993634	1068819	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ P°	3/2—5/2	2
1.89 × 10 ⁻¹	80	1344.400	1344.388	995477	1069861	2s ² 2p ⁴ (³ P)3s	2s ² 2p ⁴ (³ P)3p	⁴ P— ⁴ P°	1/2—3/2	2

^a Weighted oscillator strengths for atomic transition obtained by the method described in § 2.

^b Observed line intensities.

^c Wavelength corresponding to the energy levels difference between the experimental adjusted energy level values.

^d Numerical values of the energy levels are those obtained by an optimized procedure using the program ELCALC.

^e Level designations for the transition, including configuration parentage, term, and total angular momentum. For practical purposes, we show them in three separate columns.

REFERENCES.—(1) Ferner 1941; (2) Artru & Brillet 1977; (3) Griffin et al. 1976; (4) Träbert et al. 1976; (5) Trigueiros et al. 1992; (6) Trigueiros et al. 1991.

Since the natural lifetime $\tau(\gamma J)$ is the inverse of the probability $P(\gamma J)$, then

$$\tau(\gamma J) = [\sum A(\gamma J, \gamma' J')]^{-1}. \quad (9)$$

Natural lifetime is applicable to an isolated atom. Interaction with matter or radiation will reduce the lifetime of a state.

The values for gf and lifetime given in Tables 1 and 2, respectively, were calculated according to these equations.

In order to obtain better values for oscillator strengths, we calculated the reduced matrix elements P^1 by using optimized values of energy parameters, which were adjusted from a least squares calculation. In this adjustment, the

code tries to fit experimental energy values by varying the electrostatic parameters. This procedure improves σ -values used in equation (2) and $y_{\beta J}''$ - and $y_{\beta' J'}''$ -values used in equation (6). The energy parameters of this calculation are given by Coutinho (1998).

3. DISCUSSION

The theoretical predictions for the energy levels of the configurations were obtained by diagonalizing the energy matrices with appropriate Hartree-Fock relativistic (HFR) values for the energy parameters. For this purpose the computer code developed by Cowan (1981) was used. The interpretation of the configuration level structures were made by

TABLE 2
LIFETIMES FOR THE Si VI SPECTRUM

Configuration	Terms	Energy (cm ⁻¹)	Lifetimes ^a (ns)	Configuration	Terms	Energy (cm ⁻¹)	Lifetimes ^a (ns)
2s ² 2p ⁵	² P _{3/2}	0	...	2s ² 2p ⁴ (³ P ₀)4f	[3] _{7/2}	1413456	0.0490
	² P _{1/2}	5090	...		[3] _{5/2}	1413490	0.0492
2s ² 2p ⁴ (³ P)3p	⁴ P _{5/2}	1068819	1.4030	2s ² 2p ⁴ (¹ D ₂)4f	[1] _{1/2}	1452628	0.0436
	⁴ P _{3/2}	1069861	1.4080		[1] _{3/2}	1452628	0.0436
	⁴ P _{1/2}	1071134	1.4260		[5] _{9/2}	1453827	0.0533
	⁴ D _{7/2}	1078940	0.8989		[5] _{11/2}	1453827	0.0534
	⁴ D _{5/2}	1080706	0.9293		[2] _{5/2}	1453877	0.0448
	⁴ D _{3/2}	1082218	0.9215		[2] _{3/2}	1453888	0.0450
	⁴ D _{1/2}	1083009	0.9173		[3] _{5/2}	1455132	0.0472
	² D _{5/2}	1086801	1.1280		[3] _{7/2}	1455132	0.0471
	² D _{3/2}	1089553	1.1220		[4] _{7/2}	1455537	0.0500
	² P _{3/2}	1092176	1.0390		[4] _{9/2}	1455550	0.0500
	⁴ S _{3/2}	1093758	0.6452	2s ² 2p ⁶	² S _{1/2}	406497	0.0304
2s ² 2p ⁴ (¹ D)3p	² F _{5/2}	1123549	1.0950	2s ² 2p ⁴ (³ P)3s	⁴ P _{5/2}	990523	12.2100
	² F _{7/2}	1124218	1.0690		⁴ P _{3/2}	993634	0.7507
	² D _{3/2}	1134085	0.7971		⁴ P _{1/2}	995477	3.2690
	² D _{5/2}	1134500	0.7966		² P _{3/2}	1005436	0.0105
	² P _{3/2}	1147905	0.2301		² P _{1/2}	1009122	0.0103
	² P _{1/2}	1150287	0.2272	2s ² 2p ⁴ (¹ D)3s	² D _{5/2}	1041417	0.0259
2s ² 2p ⁴ (¹ S)3p	² P _{3/2}	1182804	0.7199		² D _{3/2}	1041477	0.0261
2s ² 2p ⁵ (³ P)3s	² P _{3/2}	1375836	0.0214	2s ² 2p ⁴ (¹ S)3s	² S _{1/2}	1094444	0.0230
	² P _{1/2}	1378824	0.0207	2s ² 2p ⁴ (³ P)3d	⁴ D _{7/2}	1181173	0.4124
2s ² 2p ⁴ (³ P ₂)4f	[4] _{7/2}	1406975	0.0511		⁴ D _{5/2}	1181655	0.4081
	[3] _{5/2}	1407118	0.0485		⁴ D _{3/2}	1182317	0.3847
	[3] _{7/2}	1407304	0.0483		⁴ D _{1/2}	1182900	0.3516
	[2] _{3/2}	1407565	0.0474		⁴ F _{9/2}	1189850	0.3442
	[2] _{5/2}	1407753	0.0493		⁴ F _{7/2}	1191546	0.3447
	[4] _{9/2}	1408106	0.0486		⁴ F _{5/2}	1193227	0.1392
	[5] _{11/2}	1408279	0.0520		⁴ F _{3/2}	1194332	0.0313
	[5] _{9/2}	1408316	0.0523		⁴ P _{1/2}	1194905	0.2546
	[1] _{1/2}	1408512	0.0467		² F _{7/2}	1194993	0.0363
	[1] _{3/2}	1408632	0.0474		⁴ P _{3/2}	1195990	0.2480
2s ² 2p ⁴ (³ P ₁)4f	[2] _{3/2}	1411464	0.0472		² F _{5/2}	1197153	0.0143
	[2] _{5/2}	1411527	0.0477		⁴ P _{5/2}	1197733	0.2094
	[4] _{9/2}	1411779	0.0507		² P _{1/2}	1200714	0.0143
	[4] _{7/2}	1411848	0.0514		² D _{3/2}	1201002	0.0046
	[3] _{7/2}	1412373	0.0490		² D _{5/2}	1202880	0.0049
	[3] _{5/2}	1412460	0.0498		² P _{3/2}	1204647	0.0131
2s ² 2p ⁴ (¹ D)3d	² G _{9/2}	1232671	0.3386	2s ² 2p ⁴ (³ P)4d	⁴ F _{7/2}	1397433	0.1884
	² S _{1/2}	1239194	0.0024		⁴ F _{5/2}	1399117	0.0216
	² P _{3/2}	1241035	0.0024		⁴ F _{3/2}	1399439	0.0252
	² F _{5/2}	1242190	0.0621		⁴ P _{3/2}	1400877	0.0779
	² P _{1/2}	1242408	0.0024		⁴ P _{5/2}	1401755	0.1184
	² F _{7/2}	1242670	0.3731		² P _{1/2}	1402472	0.0163
	² D _{5/2}	1243012	0.0037		² F _{5/2}	1402796	0.0142
	² D _{3/2}	1243878	0.0032		² P _{3/2}	1406317	0.0118
2s ² 2p ⁴ (¹ S)3d	² D _{5/2}	1291505	0.0139		² D _{5/2}	1404870	0.0142
	² D _{3/2}	1291798	0.0129		² D _{3/2}	1403085	0.0083
2s ² 2p ⁴ (³ P)4s	⁴ P _{5/2}	1323746	0.0834	2s ² 2p ⁴ (¹ D)4d	² G _{7/2}	1441668	0.1595
	⁴ P _{3/2}	1326302	0.0659		² G _{9/2}	1441758	0.1603
	⁴ P _{1/2}	1328637	0.0804		² S _{1/2}	1444335	0.0075
	² P _{3/2}	1329941	0.0414		² D _{5/2}	1445003	0.0123
	² P _{1/2}	1332772	0.0367		² P _{3/2}	1445027	0.0068
2s ² 2p ⁴ (¹ D)4s	² D _{5/2}	1371884	0.0520		² F _{7/2}	1445156	0.2212
	² D _{3/2}	1371913	0.0535		² D _{3/2}	1445575	0.0103
2s ² 2p ⁴ (³ P)4d	⁴ D _{7/2}	1392755	0.1500	2s ² 2p ⁴ (¹ S)4d	² D _{5/2}	1497095	0.0668
	⁴ D _{5/2}	1392988	0.1576	2s ² 2p ⁴ (³ P)5d	² D _{5/2}	1497653	0.0068
	⁴ F _{9/2}	1396306	0.1762	2s ² 2p ⁴ (¹ D)5d	² S _{1/2}	1538386	0.0102

^a Lifetimes for the energy level obtained by the method described in § 2.

a least squares fit of the observed levels. More details of the calculations and the tables with the theoretical Hartree-Fock parameters and their fitting values can be found in Coutinho (1998). The energy level values were determined

from the observed wavelengths by an interactive optimization procedure using the program ELCALC (Radziemski & Kaufman 1969), in which the individual wavelengths are weighted according to their uncertainties.

The energy levels adjusted by this method were used to optimize the electrostatic parameters by a least squares procedure, and finally these optimized parameters were used again to calculate the gf - and lifetimes values. This method produces gf -values that are in better agreement with line intensity observations and lifetimes values that are closer to the experimental ones.

We have presented oscillator strengths and lifetimes for all known electric dipole transitions in Si VI. The present work is part of an ongoing program, whose goal is to obtain weighted oscillator strength, gf , and lifetimes for elements of astrophysical importance. The work for Si III, Si V, and Si

VI were concluded, Callegari & Trigueiros (1998), Trigueiros & Jupén (1996), and Coutinho & Trigueiros (1998). In this particular work on Si VI, the results are part of Coutinhos's M. Sc. thesis that is in preparation.

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REFERENCES

- Artru, M.-C., & Brillet, W.-Ü. L. 1977, *Phys. Scr.*, 44, 191
Callegari, F., & Trigueiros, A. G. 1998, *ApJS*, 119, 181
Coutinho, L. H. 1998, M. Sc. thesis, Univ. Est. de Campinas, in preparation
Coutinho, L. H., & Trigueiros, A. G. 1998, *ApJS*, 115, 315
Cowan, R. D. 1981, *The Theory of Atomic Structure and Spectra* (Berkeley: Univ. California Press)
Ferner, E. 1941, *Ark. Mat. Astron. Fys.*, 28A, 21
Griffin, P. M., Pegg, D. J., & Sellin, I. A. 1976, in *Beam-Foil Spectroscopy*, 1, 321
Kelly, R. L. 1987, *J. Phys. Chem. Ref. Data*, 16, 283
Moore, C. E. 1971, *Nat. Stand. Ref. Data Ser. 35, Atomic Energy Levels* (Washington: NBS), 1
Radziemski, L. J., & Kaufman, V. 1969, *J. Opt. Soc. Am.*, 59, 424
Sobelman, I. 1979, *Atomic Spectra and Radiative Transitions* (Berlin: Springer)
Söderqvist, J. 1934, *Nova Acta Reg. Soc. Sci. Uppsala* (IV), 9, 7
Träbert, E., Heckmann, P. H., Buttlar, H. v., & Brand, K. 1976, *Z. Physik A*, 279, 127
Trigueiros, A. G., & Jupén, C. 1996, *J. Quant. Spectrosc. Radiat. Transfer*, 42, 713
Trigueiros, A. G., Jupén, C., & Redfors, A. 1991, *Phys. Scr.*, 44, 191
———. 1992, *J. Phys. B*, 25, 2765